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Psychological and Physiological Effects of
Muzzle and Breech Blast (U)

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Psychological and Physiological Effects of

Muzzle and Breech Blast (u)

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INTRODUCTION

Preliminary to a study such as this, it is necessary to conduct a thorough search of the literature relevant to the area of investigation. It is the duty of the investigator to select the pertinent facts, relate them to the problem at hand, and indicate the direction the study is to take. These are the three aims of this paper. The exact design, methodology, results, and evaluation of the study will appear in a subsequent paper.

It should be stated at the outset that no attempt will be made to offer a complete or critical review of the literature. There are some five publications available which offer quite complete reviews of the biological effects of blast, as well as several other relevant but less complete papers, such as that by Minor (22). These five primary sources are Clemedson (6), those contained in German Aviation Medicine World War II, by Schardin (24), Benzinger (1), Rössle (23), Desaga (8), a National Research Council Report (30), Meade and Eckenrode (20), and White (25). It is felt that these five sources, with particular emphasis on the review by White (25), provide an excellent critical review of what is known about the effects of blast on man.

PHYSICAL NATURE OF BLAST

The following description of the physical nature of the blast phenomena is from an unpublished paper prepared for the Human Engineering Laboratory by Minor (22): The blast wave generated by the detonation of an explosive is characterized by a very rapid rise in pressure to a peak value, and the decline of this peak pressure as an exponential function of time. The time it takes this peak pressure to fall off to zero is called the positive phase duration. Following the positive phase the pressure falls below the ambient atmospheric pressure. The duration of this transient negative pressure is known as the negative phase. Although in duration the negative phase is approximately five to six times longer than the positive phase, it never exceeds more than a fraction of the ambient atmospheric pressure existing in the undisturbed medium. A so-called classical blast wave is one that has a very short rise time, in the order of one microsecond or less, from ambient atmospheric pressure to the peak positive pressure occurring. When a blast wave strikes an object, a reflected pressure occurs which does not obey the normal laws governing reflected pressures for acoustical phenomena, in that value of the reflected blast pressure can be more than two times that of the incident pressure. Actually, the reflected pressure of a blast wave as a function of shock strength can, for an infinite shock strength, approach eight times that of the incident blast wave. A blast wave, per se, is a discontinuity in the medium, and is characterized by a nearly instantaneous pressure rise, moving at a velocity which exceeds the normal velocity of sound in the medium. This shock wave velocity is a function of the peak

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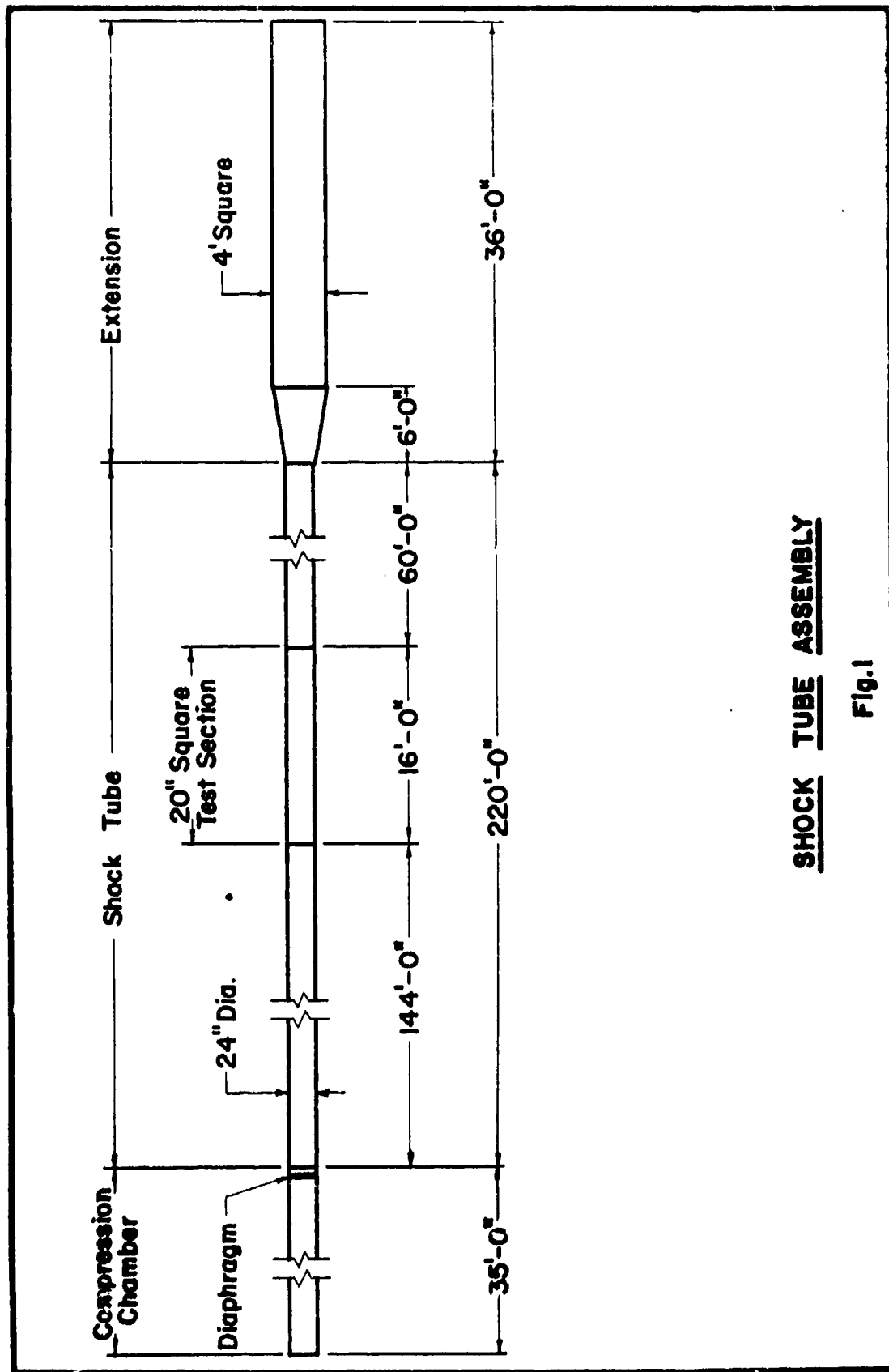
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positive pressure. Behind the sharp pressure rise there is a mass motion of the air, giving rise to a dynamic pressure. This dynamic pressure is simply related to the peak positive pressure for air considered as a perfect gas. Normally, when air is a transport medium, a classical blast wave occurs for HE explosions.

Field studies using HE charges are a very expensive experimental means and are restricted to positive phase durations of a few milliseconds, with considerable variations in peak pressures occurring due to fluctuations in charge performance. It is of great advantage to the investigator if the physical nature of the blast wave can be determined before the blast and specified from one blast to another. One such way of meeting these aims is through the use of a compressed air operated shock tube, such as that described by Celander, Clemenson, Ericsson and Hultman (5). Cassan, Curtis, and Kistler (3), and Cassan, Kalian, and Gass (4) also have used a compressed air tube to inflict blast injuries. The compressed air operated shock tube used in the present study is unique chiefly in terms of size, strength, and duration of the blast wave generated. This tube (See Figure 1) is a part of the facilities of the Explosion Kinetics Branch, Terminal Ballistics Laboratory, Ballistics Research Laboratories, Aberdeen Proving Ground, Maryland. It consists of a round steel tube 24 inches in diameter, 220 feet long with compression chambers of various lengths (6, 10, 35 feet) at one end. Affixed to the other end is an open ended extension which is 30 feet long and 4 feet square (cross section). The compression chamber and tube proper are $\frac{3}{4}$ inches thick and the extension is made of $\frac{1}{2}$ inch steel plate. It is in this extension that most of the work on this study may be done. To produce a blast, a metal diaphragm is inserted between the compression chamber and shock tube proper. The compression chamber is forced against the shock tube (with the diaphragm between) and held there by means of hydraulic jacks. The compression chamber is filled with air from compressors until the chamber pressure obtained will produce the desired peak positive pressure of the blast wave. A hydraulically operated, sharp tipped metal striker is then released which punctures the diaphragm. The built up pressure is now released, bursting the diaphragm and generating a blast wave that travels down the length of the tube. The thickness of the metal diaphragm used is determined by the maximum pressure in the compression chamber just prior to release.

The two most important components of a blast wave, with regard to damage, are probably peak positive pressure and positive phase duration. The peak pressure of the incident wave is a function of the chamber pressure which is released. The duration of the positive phase is subject to three major determinants. One is the rarefaction wave which is reflected from the diaphragm against the closed end of the compression chamber and back down the shock tube. Since the gas particles in the incident wave are already moving in this direction, the velocity of the rarefaction wave will be increased. As the rarefaction wave catches the incident wave front, the duration will be reduced toward zero. The second determinant of duration is the length of the compression chamber. The longer the compression chamber, the longer it takes the rarefaction wave to reflect off the closed end and catch the incident wave front and consequently the longer the duration. The third determinant is the rarefaction wave caused by the dispersal of the wave front when it leaves the extension. This rarefaction at the end of the extension also limits the positive phase duration. Positive phase duration is thus directly related to the distance from the open end of the extension to the target.

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SHOCK TUBE ASSEMBLY

Fig. 1

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Any object placed in the shock tube or extension will of course, be subject to more than the static peak pressure of the ideal blast wave because of reflection phenomena. This reflected pressure, in an open ended chamber such as the extension, will be slightly less than three times the static peak pressure of the blast wave proper but of relatively short duration in relation to the duration of the positive phase. The extension with dimensions of 4 feet by 4 feet allows a moderately large object to be used without the probability of waves being reflected by the object to the sides of the extension and back on the object again. If the distance between the object and the sides is short and if the object is relatively long, multiple reflections occur resulting in several spikes or peaks in the pressure-time curve. Measurements taken in the shock tube or extension permit definitive statements about rise time, peak pressure, positive phase duration, peak negative pressure, and negative phase duration. The form of the wave itself at the point of interest is available for analysis.

One final word is in order. The 20 inch square (cross section, inside dimensions) test section shown in Figure 1 is ordinarily used in testing objects in the shock tube. This square test section does not distort the wave form significantly, nor does it affect peak overpressure or duration. It is possible to use this section in the present study.

B I O L O G I C A L E F F E C T S O F B L A S T

The review of the biological effects of blast in 1954 by White (25) undoubtedly offers the most comprehensive coverage of the experimental results in this field. At the risk of oversimplification we will consider that there are two aspects of this area which are of primary importance to the study. One is the kind of injury produced as a function of specific blast parameters of known values. The aim of the work in this area is to specify the combinations and values of blast parameters which produce specific injury and which are fatal. The second aspect is a problem of scaling: that is, relating injury caused by blast of given values to any species, individual, or biological system. Implicit in both of these aspects is the problem of adequately defining and identifying the mechanisms of blast injury.

BLAST INJURIES AND ASSOCIATED GENERAL MECHANISMS

In the main, the only systematic experimental work accomplished has been within rather narrow limits. According to White perhaps the most severe of the limitations is that "No data were found concerning the dog or any other animal which indicated what the minimal, peak static overpressure for fatality or injury might be when the duration of a single positive pulse was longer than about 12 msec." (25, p.5) Actually, almost all of the systematic experimental work has been done using airblast produced by HE or through the use of a shock tube.

Post mortem examination of animals killed by exposure to blast have revealed the following major findings according to White (25):

1. Heart failure due to severely contused hearts is reported by Schlomka (quoted by Benzinger (1), Rössle (23), and Desaga (8)).
2. Arterial air embolism involving at least the coronary and cerebral arteries of most of the animals is reported by Benzinger (1), Rössle (23), and Desaga (8). At one time, Clemedson explicitly denied air embolism (6) but now, according to White (25, p. 34), he accepts it as the major cause of blast fatality.
3. Laryngeal, tracheal, and pulmonary hemorrhage are often reported. See, for example, Hooker (18), Clemedson (6), Benzinger (1), Rössle (23), the NRC report (30), and Zuckerman (28). Pulmonary hemorrhage ranges in size from focal areas to entire lungs.
4. Pulmonary edema is also reported by Hooker (18), Clemedson (6), Benzinger (1), and Rössle (23).
5. Rupture of the lungs involving emphysematous lesions, subpleural blebs and production of pneumothorax is reported by Clemedson (6), Benzinger (1), Rössle (23), the NRC report (30), Krohn, et al. (19), and Zuckerman (28).
6. Perforation and rupture or laceration of abdominal organs, particularly those containing air is reported by Clemedson (6), Benzinger (1), Rössle (23), and the NRC report (30).
7. Sinus and middle ear erythema and hemorrhage was found by Benzinger (1), Rössle (23), and the NRC report (30).
8. Ruptured ear drums and disruption of the ossicles of the middle ear is reported by White (25).
9. Inconsistent reports of hemorrhage and softening of the intracranial nervous tissue and hemorrhage and contusion of the spinal meninges and spinal nerve roots is reported by Clemedson (6), Benzinger (1), Rössle (23), and the NRC report (30).

Minor (22) gives the following general picture of how physiological changes are brought about by a classical blast wave. The incident wave has an effect on the object as though it were struck by a solid. After the blast wave has passed to the rear of the object the forces on the object are essentially drag forces due to the mass motion of the air behind the shock front. The blast wave striking the center of the exposed face of the object causes a signal to be transmitted from the center of the object to the edges at the existing velocity of sound. This signal determines the fact that a lower pressure exists at the sides of the object than at the center. This signal then transmits back to the center the fact of unequal pressure at the sides and an equalizing flow occurs from the center to the edges, resulting in a stagnation pressure. The object then becomes immersed in the wave resulting in drag forces on the object. The mechanical effects associated with these facts, in regard to physiological damage, other than distension, are as follows:

1. The incident wave will cause resonance of the structural members of the body at their own natural frequencies.

2. The drag forces resulting when the body is immersed in the flow will tend to produce forces causing a translation of the body.

According to Minor (22, p. 14), this means that "It is interesting to note that this phenomena can occur to discrete exposed parts of the body as a function of their immersion time in the blast. In other words, it can be looked at not only as affecting separate appendages, but the body as a whole, i.e. it would be possible that the drag forces would occur on a finger lifted up at an earlier time in the phenomena than the passage of the blast wave around the body as a whole, due to its greater dimensions in the direction of flow. So you then have drag forces imposed on a smaller object at a shorter time and at a higher pressure level than drag forces applied to the entire body. This effect can cause mechanical stresses between exposed parts of the body. Depending on the natural frequency of the structure excited, as compared to the duration of the blast wave, bone structure and/or cavities in the body can be distended or distorted from their normal position. As the body becomes immersed, the higher external pressure will tend to squeeze the entire body. Ear drums can be deformed under the pressure pulse as a function of this duration as related to the natural period of the membranes and bone system to cause damage at specific pressure levels. In other words, in considering the response of the body to a blast wave, the structural constants of the excited members or parts should be considered as related to the impulse of the blast wave. If a small HE blast is considered of very short duration, much shorter than a natural period of the part to be excited, little total displacement may occur and great resistance to the blast experienced. On the other hand, if the duration is as long as the natural period of the part of the body to be excited, or longer, not only will the part be resonated, but maximum deformation may occur and maximum damage be suffered. This fact, with regard to studies of blast phenomena on human beings, makes scaling from very small animals to the effect on humans, difficult."

BLAST COMPONENTS AND VALUES ASSOCIATED WITH INJURY

The picture of the blast component values associated with physiological damage is at best incomplete and inconclusive. Much of this is due to the fact that the systematic investigation has been very limited and within rather narrow confines. This is particularly true of duration. The gap between HE duration investigation, some 12 msec., and atomic-hydrogen durations, up to 1 sec. or longer, is tremendous. Perhaps the best manner of presentation is to first offer what is known and then to point out the areas where inconsistencies and lack of knowledge lies. White (25, p. 43-44) gives the following summary:

1. The duration of blast (positive phase) markedly influences the magnitude of the overpressure associated with fatality. In this connection Desaga (8) presents a table which indicates that fatal overpressure may

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decrease by a factor of 3 when the overpressure duration is increased by a factor of 7.

2. The peak static overpressure accompanying physiological damage decreases as the duration rises (up to 12 msec.) for both air and water blast.

3. Significant damage can occur when peak static overpressure is within 12.5 - 25 psi for the dog and chimpanzee; as low as 31 psi for the human chest and nervous system and as little as 4 - 6 psi for the human ear drum for HE generated blasts of a few milliseconds duration.

4. Peak pressure, momentum and energy alone do not provide reliable indications of damage.

5. Wind loadings may be of considerable importance.

6. The relation between the time and magnitude characteristics of the blast wave and the natural period of the biological system may be of critical importance.

7. In cases where pressure, momentum and energy of the primary pulse appear minor and where damage occurs, secondary loads or repetitive pulses may be very important.

In addition to the points listed above the following information is relevant. Hooker (18) exposed animals near the muzzles of mortars and 10 and 12 inch rifles. Near the mortars 338 psi overpressure did not prove fatal. Near the rifles 281 psi was damaging and sometimes fatal. Although not measured, the duration near the rifles was much larger than around the mortars.

Fisher, Krohn, and Zuckerman (9, 10) exposed mice, guinea pigs, and rabbits to HE blasts to determine the LD-50 (lethal dosage of 50% of the animals) for each species. The duration was from 1 - 3 msec., and LD-50 overpressures for each species was 26 psi for the mouse, 32 psi for the guinea pig, and 55 psi for the rabbit. Fisher et al. derived a formula relating body surface area (a function of body weight), and LD-50 pressure. Monkeys and goats were exposed to blast and the resulting LD-50 pressures were around 100 psi for monkeys and around 175 for goats. These values are reasonably in agreement with the predicted values. The authors extrapolated their curve to yield values for 132 lb. and 176 lb. men and obtained values of 390 and 470 psi respectively. This agrees fairly well with British casualty survey work during World War II (9, 10). All of this work applies only to HE explosions in the open, with overpressures that do not have long durations.

Desaga (8) using Schardin's (24) data reports human fatality at 235 psi but the duration was not known and repeated pulses were probable since the persons were in shelters.

Clemedson (6) working in the field with open HE explosions and in a detonation chamber killed some animals (rabbits) as low as 56.9 psi. However, the LD-50 pressure is above 285. White feels that the apparent discrepancy between the results reported by Fisher et al. and Clemedson is partially due to different means of measurements, different positions of the animals relative to the explosion, and possible different durations (Clemedson did not report durations for each blast).

Recent work done involving human volunteers and underwater blast conditions is discussed by White (25, p. 20). It is in this work that damage has been found as low as 31 psi.

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The failure of Schardin and Fisher's LD-50 pressures for humans to agree and the lack of correspondence between Clemedson and Fisher's results with rabbits indicate the lack of exact knowledge in this area. Generally the problem has been one of failure to accurately measure the significant blast variables, or failure to specify them at all. Quantitative agreement among results cannot be expected unless the parameters and their values agree, or unless the relationships between blast components are fully described and properly interpreted.

SCALING PROBLEMS

The problem of scaling eventuates itself in predicting effects of blast on man when only effects on smaller animals is known. The work by Fisher et al. referred to above did exactly this and their results seemed to fairly well validate their formula.

$$P50 = 23.7 / 0.24 W^{2/3}, \text{ where}$$

P50 = 50% probability of fatality and

W = weight of the animal.

However, as was stated above, these results apply only to HE type explosions in the open, where overpressures do not vary in rate of rise, and which do not have long durations (exceeding a few msec.).

In addition to these qualifications one more should be mentioned. This is that both whole organic bodies and parts of the bodies have natural frequencies which, in combination with a particular blast wave, very probably markedly influence the kind and amount of physiological damage. Minor (22) and White (25), both feel that the relation between the natural period of the body and the time of the duration of the blast is very significant.

One last point should be made regarding the biological effects of blast. The Frankford Arsenal Report (29) concludes that the maximum safe peak overpressures for humans is $2\frac{1}{2}$ - $3\frac{1}{2}$ psi. This is based in part on Williams (26) and in part on Young (27). Neither of these reports provides a rigid experimental basis for fixing these limits. The statement by Williams (26, p. 40) that "the maximum blast pressure that can be withstood without loss of efficiency is $2\frac{1}{2}$ lbs. per square inch" has no satisfactory referent for the term "loss of efficiency". Nevertheless, it is well to bear in mind that this low limit of pressure has been recommended and may, under certain circumstances, be meaningful. The Frankford Report (29) also states that due to a difference in gauges used, the American Naval studies report the $3\frac{1}{2}$ psi as 7 psi or twice the pressure of the shock front.

PSYCHOLOGICAL EFFECTS OF BLAST

There is a fundamental distinction in this area which should be made. Some psychological effects of blast have detectable physiological changes as concomitants; some do not. In this paper "psychological effects" refers primarily to measurable changes in behavior regardless of the presence or absence of physiological changes. With regard to behavior changes which have associated physiological damage, Minor (22) suggests that in addition to the previously mentioned kinds of damage, it is possible that pressure pulses arising in the body could be sufficient to produce capillary ruptures in the brain. Such possibility of damage is undoubtedly related to both the general and specific physical condition of the animal. The condition of the circulatory system would seem to be particularly important. At any rate, there is little doubt that in most cases physiological damage may be accompanied by behavioral changes.

However, both Meade and Eckenrode (20) and Minor (22) as well as the NRC Report (30), state that it is likely that psychological changes occur in response to blast, which produces little or no observable physiological damage. These psychological effects may be manifested only immediately after blast, may be continuing, or may be demonstrated only after some delay. Meade and Eckenrode (20), after surveying the available open literature, report the following as possible psychological implications of blast (without serious physiological damage).

1. Nystagmus, blurring of vision, inability to concentrate, loss of efficiency as gun crew member.
2. Feelings of extreme lethargy and fatigue. Feelings of extreme restlessness and generally diffused behavior. Pain and ringing in the ears.
3. Fear and blast concussion may produce hysterical anxiety.
4. Loss of consciousness, retrograde amnesia, tremors, and general nervousness may result.
5. Nervous tension is sometimes thought by those exposed to be the most serious result of gun blast.

The lack of a systematic body of knowledge in regard to the possible psychological effects of blast is painfully obvious. Reliable, valid information is badly needed concerning behavior changes and associated physiological changes (or their absence) resulting from blast. This information is desirable not only with regard to man, but with regard to other organisms as well.

AIMS OF THE PRESENT STUDY

Before discussing the general aims of the present study, perhaps a word of explanation is in order concerning the experimental animals to be used. The use of animals as subjects is defended on two main counts. First, the danger to humans exposed to large blasts is obvious and could not be permitted without certain knowledge that no harm would occur. Second, the use of animals as subjects, where knowledge about human problems is desired, is well established and validated. Hebb and Thompson (17) make the following two points about the social significance of animal experimentation.

1. Animal experimentation may clarify a human problem without "proving" anything.
2. Animal experimentation repeatedly has shown the treatment of human problems to be oversimplified.

Thesus monkeys (Macaca mulatta) were selected as experimental animals in the present study not only because they were readily available, but because of the wealth of psychological and physiological normative data which are available. Since the study will be concerned with psychological and physiological changes resulting from blast, the importance of having normative data can hardly be overemphasized. For an elaboration of this point, see the sections below relating to the general aims of the study.

Within the limitations of the available facilities there are two overall aims of the present study. They are first, to determine the blast fatality limits for the animals employed, and secondly, to determine the extent of behavioral change and concomitant physiological damage when the blast is sub-lethal. In regard to the first aim, determination of fatality limits, the positive phase duration will definitely not be "short", i.e., less than 15 msec., and could conceivably be as long as 220 msec. The problem here is to specify the pressure-time relationships which prove to be fatal. The practical pressure-time limitations which govern the study are approximately as follows: at 200-plus msec. 30 psi can be produced; at 20 - 60 msec. only 15 psi can be expected. The durations up to 60 msec. with pressures up to 15 psi can be produced in the extension to the shock tube (See Fig. 1), while larger durations and higher pressures are obtained only in the 20 inch square, 16 foot test section (Fig. 1). Because of the added space (4 foot square vs. 20 inch square) it is planned to do as much as possible in the extension without moving to the test section. However, if the maximum pressure-time relations in the extension do not produce fatality it is planned to work in the 20 inch square test section, even though this will mean altering slightly the position of the animal relative to the incident front of the blast wave.

With regard to the psychological phase of the program, once the fatality study is concluded, some blast parameters corresponding to those found around current Ordnance weapons will be selected and animals will be exposed to these blast conditions. There will be both acquisition and retention studies, i.e., animals exposed to blast and then training, and ani-

males trained, exposed to blast and retested. In any given study there will, of course, be a control and an experimental group. The first psychological testing program will encompass three general areas of behavior. These are:

1. Sensory and motor tests.
2. Learning
3. Complex manipulation

The sensory and motor tests are essentially those described by Cole (7) and Glees and Cole (11) and consist of tests for motor power, ability to tactually discriminate solids, and dexterity ability. The learning tests will be a discrimination test such as is described by Harlow (12) and a typical delayed reaction test (21). The complex manipulation will be a puzzle test after Harlow (13). Each of these tests is well known and provides not only exact information about apparatus, design, and methodology but also normative data which can be utilized for comparison purposes.

It is planned to utilize other tests of auditory acuity (16), discontinuous pursuit (15), visual exploration (2), formation of learning sets (14), etc. There is no practical limit to the kind and number of tests that can be used in examining the behavior of monkeys. The selection of the three areas (sensory-motor, learning, and manipulation) for testing in the first part of the psychological program was governed by the consideration of those areas most likely to relate to comparable human problems.

The first phase of this study, determination of fatality limits, is now under way. The design, methodology, and results of the fatality study will constitute the next report of this project.

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